2018 7th OKUCC (OpenFOAM Korea Users' Community Conference)

유체-지반 연성 코드 작성 및 문제 해결

2018. 11. 1 ~ 2

서울대학교 글로벌 컨벤션 플라자

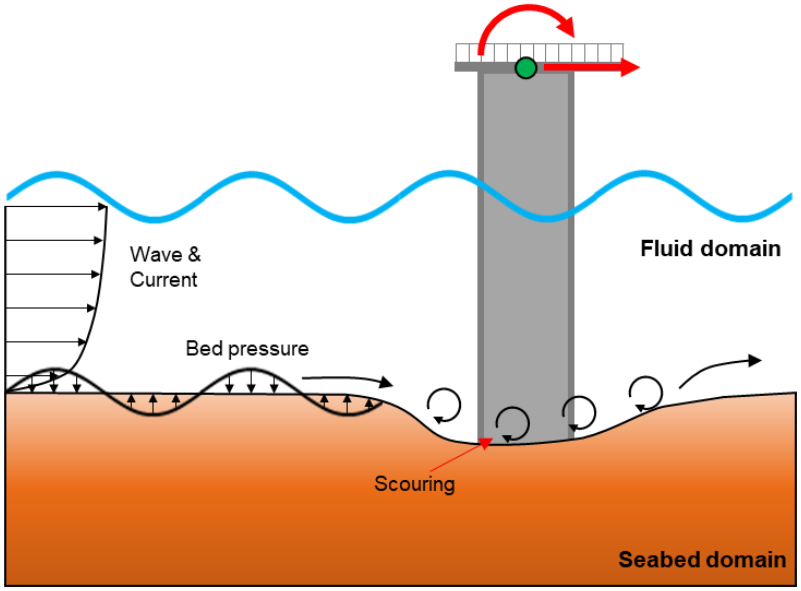
한국해양대학교 송성진, 박선호

INDEX

도입부

□ 연구배경

- 해저지반의 불안정성으로 인한 기초 구조물의 구조적 파괴
- 액상화와 세굴현상에 의한 침하 파괴
- 해저지반-파랑/해류-구조물의 상호작용에 대한 연구 필요



□ 연구목적

- 파랑과 해류를 고려한 환경하중에서 해저지반의 반응에 따른 모노파일 주위 세굴 현상에 대한 수치해석

수치해석 방법

□ 유체-구조 연성 해석 기법

- 집적(monolithic) 기법
  - 유동장과 구조물의 변형을 하나의 계로 간주하여 계산
- 분할(partitioned) 기법
  - 유동장과 구조물의 변형을 각각의 도메인에서 계산
  - 도메인의 공통 경계면을 통하여 유체력을 전달하고 구조물의 변형 및 변위 정보를 반영
  - 단방향(one-way coupling)연성과 양방향(two-way coupling)연성
  - 단방향 연성은 한 시간 단계에서 유체에서 구조로 전달하기 때문에 구조물의 변형이 크지 않은 유체-구조 문제에 적합
  - 양방향 연성은 한 시간 단계에서 유체와 구조에 대한 정보를 양방향으로 전달하기 때문에 복잡한 유체-구조 문제에 적합
  - 본 연구에서는 유체력에 의해 변형된 해저지반을 고려한 세굴현상을 해석(양방향 연성)

시행 착오

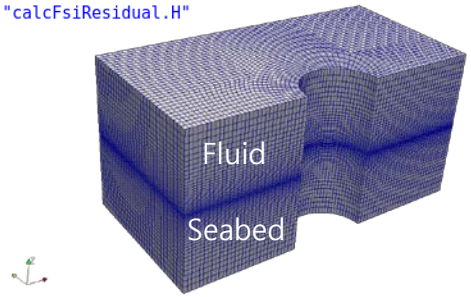
☐ Cylinder mesh using blockMesh

faceInterpolate() faceInterpolate()

fluid.faceCentres solid.faceCentres fluid.Pressure.face solid.Pressure.face pp.seabed.face()

	fluidPatch.cellCentre		fluidZone.cellCentre		solidPatch.cellCentre		difference	fluidPatchPressure	fluidZonePressure	solidPatchPressure	solidZonePressure	pp.boundaryField()	pp.boundaryField()[solidPatchID
2	-1.97494	0.0354704	-1.97494	0.0354704	-1.97494	0.0354704	0	78083.9	78083.9	78083.9	78083.9	0	78083.9
3	-1.97479	0.106405	-1.97479	0.106405	-1.97479	0.106405	0	77993	77993	77993	77993	0	77993
4	-1.97448	0.17732	-1.97448	0.17732	-1.97448	0.17732	0	77813.6	77813.6	77813.6	77813.6	0	77813.6
5	-1.97403	0.248202	-1.97403	0.248202	-1.97403	0.248202	0	77548.6	77548.6	77548.6	77548.6	0	77548.6
6	-1.97343	0.31904	-1.97343	0.31904	-1.97343	0.31904	0	77204.5	77204.5	77204.5	77204.5	0	77204.5
7	-1.97268	0.389822	-1.97268	0.389822	-1.97268	0.389822	0	76785.9	76785.9	76785.9	76785.9	0	76785.9
8	-1.9718	0.460535	-1.9718	0.460535	-1.9718	0.460535	0	76301.9	76301.9	76301.9	76301.9	0	76301.9
9	-1.97079	0.53117	-1.97079	0.53117	-1.97079	0.53117	0	75759.8	75759.8	75759.8	75759.8	0	75759.8
10	-1.96965	0.601716	-1.96965	0.601716	-1.96965	0.601716	0	75169.8	75169.8	75169.8	75169.8	0	75169.8
11	-1.96839	0.672163	-1.96839	0.672163	-1.96839	0.672163	0	74542.2	74542.2	74542.2	74542.2	0	74542.2
12	-1.92486	0.0356641	-1.92486	0.0356641	-1.92486	0.0356641	0	78242.7	78242.7	78242.7	78242.7	0	78242.7
13	-1.9244	0.106974	-1.9244	0.106974	-1.9244	0.106974	0	78150.5	78150.5	78150.5	78150.5	0	78150.5
14	-1.92348	0.178228	-1.92348	0.178228	-1.92348	0.178228	0	77968.5	77968.5	77968.5	77968.5	0	77968.5
15	-1.92211	0.24939	-1.92211	0.24939	-1.92211	0.24939	0	77700.5	77700.5	77700.5	77700.5	0	77700.5

```
    do
    {
        outerCorr++;

//#           include "setInterfaceDisplacement.H"

//#           include "moveFluidMesh.H"

#           include "solveFluid.H"

#           include "setInterfaceForce.H"

#           include "solveSolidEuler.H"

//#           include "calcFsiResidual.H"

    }
```



after 1time step

previous time step present time step

_a	fluidPatchPressure	fluidZonePressure	solidPatchPressure	solidZonePressure	pp.boundaryField(	pp.boundaryField()	solidPatchID]
	277.13	277.13	277.13	277.13	78083.9	277.13	
	276.202	276.202	276.202	276.202	77993	276.202	
	273.521	273.521	273.521	273.521	77813.6	273.521	
	270.123	270.123	270.123	270.123	77548.6	270.123	
	263.514	263.514	263.514	263.514	77204.5	263.514	
	257.057	257.057	257.057	257.057	76785.9	257.057	
	248.747	248.747	248.747	248.747	76301.9	248.747	
	241.093	241.093	241.093	241.093	75759.8	241.093	
	232.847	232.847	232.847	232.847	75169.8	232.847	
	223.617	223.617	223.617	223.617	74542.2	223.617	
	279.415	279.415	279.415	279.415	78242.7	279.415	
	278.636	278.636	278.636	278.636	78150.5	278.636	
	276.251	276.251	276.251	276.251	77968.5	276.251	
	272.228	272.228	272.228	272.228	77700.5	272.228	
	265.589	265.589	265.589	265.589	77352.6	265.589	

시행 착오

☐ Cylinder mesh using snappyHexMesh

faceInterpolate()

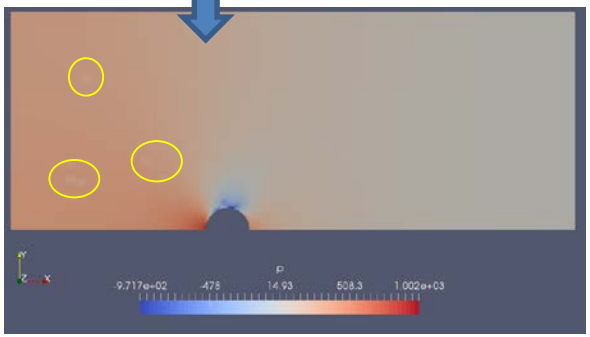
fluid.faceCentres solid.faceCentres

faceInterpolate()

fluid.Pressure.face solid.Pressure.face pp.seabed.face()

	fluidPatchFaceCentres		fluidZoneFaceCentres		solidPatchFaceCentres		solidZoneFaceCentres		difference	fluidPatchPressu	fluidZonePressure	solidPatchPressure	solidZonePressure	difference	pp.boundaryFi	pp.boundaryFi
2	-4.91642	0.0367999	-4.91642	0.0367999	-4.91642	0.0367999	-4.91642	0.0367999	0	30278.2	30278.2	30278.2	30278.2	0	0	30278.2
3	-4.91644	0.110796	-4.91644	0.110796	-4.91644	0.110796	-4.91644	0.110796	0	30272	30272	30272	30272	0	0	30272
4	-4.91641	0.185636	-4.91641	0.185636	-4.91641	0.185636	-4.91641	0.185636	0	30259.6	30259.6	30259.6	30259.6	0	0	30259.6
5	-4.91642	0.261343	-4.91642	0.261343	-4.91642	0.261343	-4.91642	0.261343	0	30240.7	30240.7	30240.7	30240.7	0	0	30240.7
6	-4.91642	0.337928	-4.91642	0.337928	-4.91642	0.337928	-4.91642	0.337928	0	30215.2	30215.2	30215.2	30215.2	0	0	30215.2
7	-4.91642	0.415431	-4.91642	0.415431	-4.91642	0.415431	-4.91642	0.415431	0	30183.1	30183.1	30183.1	30183.1	0	0	30183.1
8	-4.91642	0.493869	-4.91642	0.493869	-4.91642	0.493869	-4.91642	0.493869	0	30144.1	30144.1	30144.1	30144.1	0	0	30144.1
9	-4.91642	0.573254	-4.91642	0.573254	-4.91642	0.573254	-4.91642	0.573254	0	30098.1	30098.1	30098.1	30098.1	0	0	30098.1
10	-4.91642	0.653597	-4.91642	0.653597	-4.91642	0.653597	-4.91642	0.653597	0	30045.2	30045.2	30045.2	30045.2	0	0	30045.2
11	-4.91642	0.734909	-4.91642	0.734909	-4.91642	0.734909	-4.91642	0.734909	0	29985.3	29985.3	29985.3	29985.3	0	0	29985.3
⋮																
463	-3.62687	0.90553	-3.62687	0.90553	-3.62687	0.90553	-3.62687	0.90553	0	30726.6	30726.6	30726.6	30726.6	0	0	30726.
464	-3.62682	0.989799	-3.62682	0.989799	-3.62682	0.989799	-3.62682	0.989799	0	30596.3	30596.3	30596.3	30596.3	0	0	30596.
465	-3.62677	1.07508	-3.62677	1.07508	-3.62677	1.07508	-3.62677	1.07508	0	30456	30456	30456	30456	0	0	3045
466	-3.62671	1.16139	-3.62671	1.16139	0	0	0	0	-3.62671	30306.2	30306.2	0	0	30306.2	0	
467	-3.62666	1.24875	-3.62666	1.24875	-3.62666	1.24875	-3.62666	1.24875	0	30147.6	30147.6	30147.6	30147.6	0	0	30147.
468	-3.62659	1.33715	-3.62659	1.33715	-3.62659	1.33715	-3.62659	1.33715	0	29980.6	29980.6	29980.6	29980.6	0	0	29980.
469	-3.62652	1.42662	-3.62652	1.42662	-3.62652	1.42662	-3.62652	1.42662	0	29806	29806	29806	29806	0	0	2980
470	-3.62644	1.51716	-3.62644	1.51716	0	0	0	0	-3.62644	29624.2	29624.2	0	0	29624.2	0	
471	-3.62636	1.60881	-3.62636	1.60881	-3.62636	1.60881	-3.62636	1.60881	0	29436.2	29436.2	29436.2	29436.2	0	0	29436.
472	-3.62627	1.70155	-3.62627	1.70155	-3.62627	1.70155	-3.62627	1.70155	0	29242.6	29242.6	29242.6	29242.6	0	0	29242.
473	-3.62618	1.79541	-3.62618	1.79541	-3.62618	1.79541	-3.62618	1.79541	0	29044.2	29044.2	29044.2	29044.2	0	0	29044.
474	-3.62609	1.89041	-3.62609	1.89041	-3.62609	1.89041	-3.62609	1.89041	0	28841.9	28841.9	28841.9	28841.9	0	0	28841.

Patch to patch face interpolation error



시행 착오

☐ Cylinder mesh using snappyHexMesh

faceInterpolate()

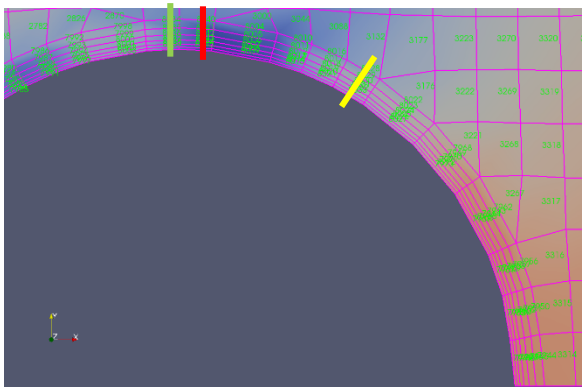
fluid.faceCentres → solid.faceCentres

faceInterpolate()

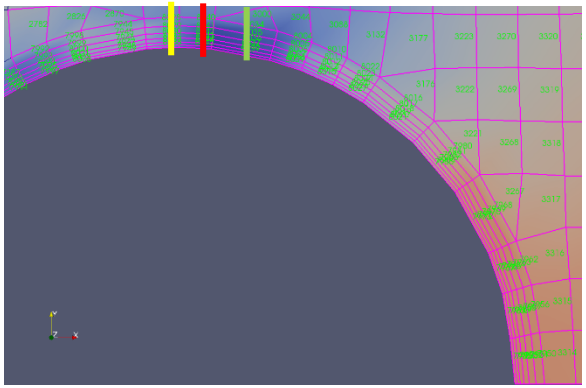
fluid.Pressure.face → solid.Pressure.face → pp.seabed.face()

1	fluidPatchFaceCentres		fluidZoneFaceCentres		solidPatchFaceCentres		solidZoneFaceCentres		difference	fluidPatchPressu	fluidZonePressure	solidPatchPressure	solidZonePressure	difference	pp.boundaryFi	pp.boundaryFi
8000	-0.0973986	0.527286	-0.0973986	0.527286	-0.169292	0.510345	-0.169292	0.51034	0.0718934	25917.3	25917.3	34224.3	34224.3	-8307		34224.
8001	-0.0953051	0.51594	-0.0953051	0.51594	-0.165665	0.499361	-0.165665	0.49936	0.0703599	26061.4	26061.4	34532.9	34532.9	-8471.5		34532.
8002	-0.0936951	0.507214	-0.0936951	0.507214	-0.162875	0.490914	-0.162875	0.49091	0.0691799	26173.9	26173.9	34760.3	34760.3	-8586.4		34760.
8003	-0.0924581	0.500502	-0.0924581	0.500502	-0.160729	0.484417	-0.160729	0.48441	0.0682709	26259.1	26259.1	34926.3	34926.3	-8667.2		34926.
8004	-0.0915046	0.49534	-0.0915046	0.49534	-0.159079	0.479419	-0.159079	0.47941	0.0675744	26322	26322	35043.3	35043.3	-8721.3		35043.
8005	-0.0907719	0.491369	-0.0907719	0.491369	-0.157808	0.475577	-0.157808	0.47557	0.0670361	26369.5	26369.5	35126.4	35126.4	-8756.9		35126.
8006	0.0989447	0.526763	0.0989447	0.526763	0.170776	0.509537	0.170776	0.50953	-0.0718313	1523.24	1523.24	-6709.49	-6709.49	8232.73		-6709.4
8007	0.0968242	0.515421	0.0968242	0.515421	0.167134	0.498558	0.167134	0.49855	-0.0703098	1365.9	1365.9	-7023.39	-7023.39	8389.29		-7023.3
8008	0.0951945	0.506698	0.0951945	0.506698	0.164332	0.490115	0.164332	0.49011	-0.0691375	1240.71	1240.71	-7249.96	-7249.96	8490.67		-7249.9
8009	0.0939411	0.499988	0.0939411	0.499988	0.162177	0.483621	0.162177	0.48362	-0.0682359	1143.67	1143.67	-7411.4	-7411.4	8555.07		-7411.
8010	0.0929748	0.494829	0.0929748	0.494829	0.160519	0.478626	0.160519	0.47862	-0.0675442	1070.26	1070.26	-7527.03	-7527.03	8597.29		-7527.0
8011	0.0922343	0.490859	0.0922343	0.490859	0.159245	0.474784	0.159245	0.47478	-0.0670107	1016.23	1016.23	-7608.04	-7608.04	8624.27		-7608.0
8012	0.170776	0.509537	0.170776	0.509537	0.221633	0.489806	0.221633	0.48980	-0.050857	-6709.49	-6709.49	-12907	-12907	6197.51		-1290
8013	0.167134	0.498558	0.167134	0.498558	0.216877	0.479264	0.216877	0.47926	-0.049743	-7023.39	-7023.39	-13296.8	-13296.8	6273.41		-13296.
8014	0.164332	0.490115	0.164332	0.490115	0.213219	0.471156	0.213219	0.47115	-0.048887	-7249.96	-7249.96	-13587	-13587	6337.04		-1358

Face numbering order의 차이로 인한 오차



Seabed_fluid_cellID

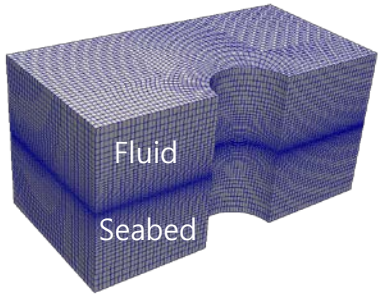


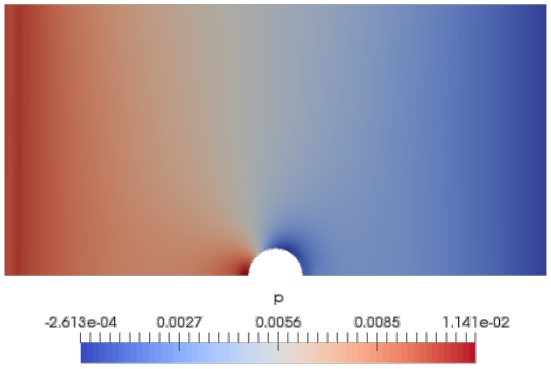
Seabed_solid_cellID

시행 착오

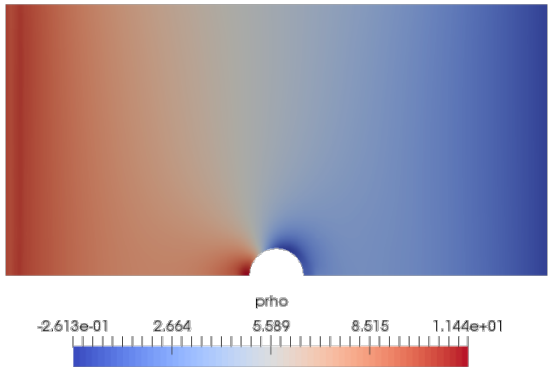
□ Cylinder mesh using blockMesh

– 단방향 연성



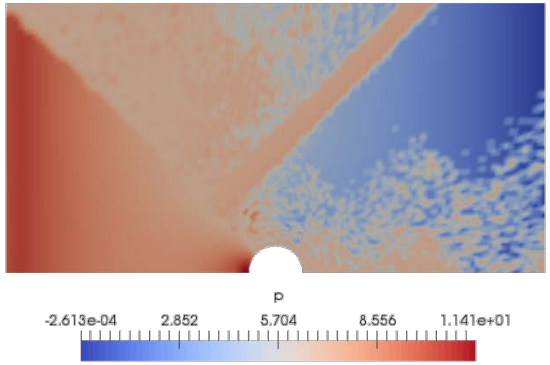


sampleDict

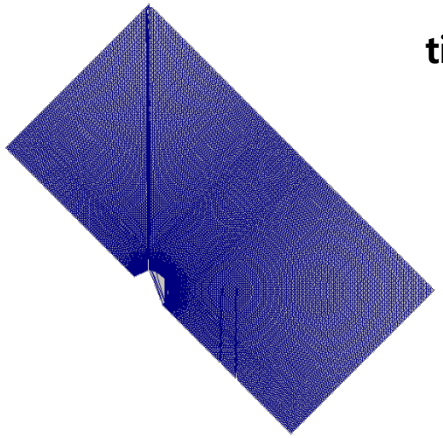


Seabed_fluid_pressure

Seabed_fluid_pressure_sampling.vtk



triangulation



Seabed_soil_pressure

Seabed_soil_pressure

timeVaryingMappedFixedValue.C

```
366
367     tmp<vectorField> tlocalVertices
368     (
369         referenceCS().localPosition(samplePoints)
370     );
371     const vectorField& localVertices = tlocalVertices();
372
373     // Determine triangulation
374     List<vector2D> localVertices2D(localVertices.size());
375     forAll(localVertices, i)
376     {
377         localVertices2D[i][0] = localVertices[i][0];
378         localVertices2D[i][1] = localVertices[i][1];
379     }
380
381     triSurface s(triSurfaceTools::delaunay2D(localVertices2D));
382
383     tmp<pointField> localFaceCentres
384     (
385         referenceCS().localPosition
386         (
387             this->patch().patch().faceCentres()
388         )
389     );
```

Conclusions

- **Data mapping**
  - 오픈폼에서 사용되는 데이터 mapping 기법에 대한 이해 필요
  - Patch to Patch interpolation 에서 face interface error 문제
  - timeVaryingMappedFixedValue 경계조건에서 삼각법 적용 문제
- 단방향 유체-구조(해저지반) 연성
  - 유체 도메인의 인터페이스 값을 해저지반 인터페이스 입력값으로 불러들일 때 point interpolation error가 발생
- 양방향 유체-구조(해저지반) 연성
  - Cylinder mesh using blockMesh
    - Face interpolation은 만족하지만 soil modeling iteration에서 발산
  - Cylinder mesh using SnappyHexMesh
    - Face interpolation error 발생
    - Cell numbering이 바뀌면서 pressure interpolate 오차 발생

THANK YOU

Q&A